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Predicting product accommodation: The role of the anthropometric fit test

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Abstract

Anthropometry is often considered in product design, but less often in prototype testing. This paper focuses on how to design, conduct and analyse a test that will consider user anthropometry and ensure that the intended user population can be accommodated by the new product. Identifying the target user is the first step in a successful test. It is critical that the sample of individuals used in the fit test should be representative of the intended market for the product, or results will be invalid. Second, the size of the test sample needs to be determined. Sample size for fit tests has to do with the adjustability or sizing of the product (if any) as well as strictly anthropometric concerns. The test design itself depends on the stage of product development. Early testing produces information that can be used to improve the product before it is released. Later, a test might be designed to help create a size selection chart for a sized product. The choice of anthropometric dimensions to be included will depend specifically on the product being tested, but also on the dimensions that have been measured on the target market population. All elements of the test protocol should be validated with a laboratory trial before actual data collection begins. Finally, the edited data should be analysed using statistical techniques appropriate to the questions being asked. In some cases, visual data displays are helpful. The analysis can predict what proportion of the target population will be accommodated.

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Keywords: Anthropometry; Fit test; User accommodation

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1. Introduction

Companies spend large amounts on the development, testing and marketing of new products. Even with effective marketing, however, the success of a product can also hinge on how well it interfaces with the user's body size and shape. Anything that has to be worn on the head, operated with the hand, or carried on the shoulder depends in part on the anthropometry of the user. Anthropometry is often considered in product design [1, 2], but less often in prototype testing. Too often a prototype is tested with the result that 87% found the item acceptable, and it did not fit 13% of users. Test results of that nature are not helpful in improving the product because there is no clear direction about what needs to be changed to improve product fit. This paper focuses on how to design, conduct and analyze a test that will consider user anthropometry and ensure that the intended user population can be accommodated by the new product.

2. Identifying the target market

Identifying the target user is the first step in a successful test. Beyond the geographic distribution—global or domestic—some products are targeted at specific age groups or specifically for men or women. For example, weight-lifting gloves may be targeted at individuals who are physically fit. The key criterion may be a body mass index (BMI) below a certain amount. For some consumer electronic products such as gaming equipment, the age range may be in the early teens through mid-adulthood. In the United States, a country with historic immigration patterns, there is considerable ethnic diversity. As there are anthropometric differences between various ethnic groups, those need to be considered in product design and testing. For example, head shapes vary between Asian-Americans and Americans of European ancestry [3], so a product that needs to fit the head should be tested on a sample that includes both Asian-Americans and European-Americans. In other parts of the world there are other factors that should be considered. In the Netherlands, a relatively small country, there are nevertheless anthropometric differences between individuals in the north and those in the south [4]. Finally, there are sometimes distinct anthropometric characteristics of certain occupational groups [5] which should be taken into account if a product or workspaces has a specific occupational focus. The factors which should be taken into account are summarized in Table 1.

Table 1. Target market characteristics for use in fit test design.

Always consider	Possibly consider, depending on product
Sex distribution	Anthropometric delimiters, such as BMI
Age distribution	Geographic range
Racial/ethnic distribution	Occupation, or product use history
	Household income level

2.1. Sample size

Determining the sample size for anthropometric survey is relatively straightforward and has become standardized [6]. The key components are the variability of the characteristic (e.g., a larger sample is required for more highly variable dimensions), the desired certainty of the results (e.g., a larger sample is required to increase the certainty of the statistical estimates) and the degree of precision needed (e.g., a larger sample is required if we need to know the group mean value to 1 millimetre, rather than needing to know it plus or minus 6 millimetres). For an anthropometric fit test however, different factors come into play. In general, we assume that basic anthropometric characteristics of the target population are known, so in creating the test sample the goal is to make sure that the ends of the range, as well as key points in the middle of the distribution, are represented in the sample. In a sized system – for example the weight-lifting gloves – the size of the sample will also depend on how many sizes of the product are intended. And, it will depend on how great an anthropometric range can be accommodated in a single size. A familiar example is men's jeans, where the waist sizes typically increase in 2-inch increments. This means that the jeans developer has determined that a given size can accommodate approximately a 2-inch range in waist circumference. A much smaller range is used when the body part has less flexibility, and where a closer fit is desired. An illustration of this is traditional men's dress shirt sizing is based on a ½-inch range in neck circumference. Typically a good rule of thumb is to have a test sample size large enough to make sure that each size of the product is tested, and that there is at least a minimum of a certain number of test participants in each size. McConville [7] identified 3 to 5 individuals as a minimum sample per size, but we suggest that number as a starting point for consideration, and that the specific characteristics of the product should influence the number of participants as well. When making those considerations, it is important to keep in mind that a larger range for each size will generally require more test participants than a smaller range. In an adjustable product, as opposed to a sized product, it may be desirable to divide the adjustment range into segments so that investigators can make certain that the whole design range is considered in testing.

2.2. Sample composition

We noted above, and summarized in Table 1 the population characteristics that are important to capture in the test sample. The question arises, 'how should those categories be represented in a sample?' In an anthropometric survey, they are typically represented in a sex X ethnicity X age matrix, such as seen in Figure 1.

A sample matrix for a fit test, on the other hand, may have rows and columns based on the sizes of the item. Consider a test plan for men's jeans, in Figure 2.

As a practical matter, it is not realistic to overlay a detailed sex-race-age matrix on a size matrix. Instead, we recommend using a fit test matrix, based on the number of sizes, but recruiting for the fit test to include representation of all the critical demographic groups. In general, the goal would be to get a test sample whose demographic characteristics roughly match the population of interest. However, if some groups are a small minority, but at the same time are anthropometrically distinct, then we recommend increasing their representation in the test sample so there are at least 5 members of the minority group. This ensures against testing one or two participants who, by chance, are strikingly *not* representative of their minority ethnic group.

It is important to point out that a test sample such as that shown in Figure 2 will *not* be anthropometrically representative of the target population. If it were anthropometrically representative, there would be many more individuals tested in the central ('medium') sizes, and many fewer in the very small and very large sizes. Yet, it is precisely those sizes that are often of interest in a fit test. Typically a product is designed for the center of the

	White		African-American		Asian		Hispanic	
Age Group	Male	Female	Male	Female	Male	Female	Male	Female
18 - 24	450	200	100	100	20	10	40	20
25-30	450	200	100	100	20	10	40	20
35-40	450	200	100	100	20	10	40	20
40+	450	200	100	100	20	10	40	20

Fig. 1. Example sample matrix for an anthropometric survey.

Inseam	Waist 32	Waist 34	Waist 36	Waist 40	Waist 42	Waist 44
30	10	10	10	10	10	10
32	10	10	10	10	10	10
34	10	10	10	10	10	10
36	10	10	10	10	10	10

Fig. 2. Example sample matrix for men's jeans fit test.

distribution, and then made larger and smaller to fit everyone. Creating the larger and smaller sizes is a source for error, so it is critical that the smallest and largest sizes are tested. Although the test sample is not anthropometrically representative, it should be as *demographically* representative as possible, meaning that the important characteristics summarized in Table 1 are all seen in the test sample.

3. Test design

The test design itself depends on the stage of product development. Ideally, the testing takes place early enough in the process that information learned in the test can be used to improve the product before it is released. A later stage test might be used to develop a size selection chart and tariff. However the test is designed, it is important to conduct dry run testing in the laboratory prior to data collection. This allows the investigators to hone their measuring skills, and to agree on the interpretation of each of the fit criteria. It also uncovers any unexpected difficulties in implementing the test protocol.

3.1. Early stage testing

For a one size or adjustable item, the test is designed to answer questions about how to improve the product. The data gathered will be specific to how the product should be changed in the next iteration to either fit a greater number of people, or to fit them better. In addition to pertinent anthropometric measurements, investigators may collect data on the offset between the item and the body, or the amount of excess dimension in the product over the body dimension. For other kinds of products, the test user may perform a series of tasks – keystrokes, or mouse movements – and the investigator will track percentage of correct movements to correlate with hand or finger size.

Sized items offer the opportunity to answer two kinds of questions can be answered with early stage testing. In addition to the questions that focus on product improvement, the test can determine the range of body size accommodated in a single size. This can be critical information in later determining the total number of sizes needed to accommodate the population. Clearly a jacket that can accommodate a 5 inch range of chest circumference can fit the same number of people in fewer sizes than a jacket with a 3 inch range of chest circumference. Testing a single size on many different sized people is known as fit-mapping [8] and is especially helpful in minimizing the number of sizes needed to accommodate a specific population range.

3.2. Later stage testing

When a product is nearing market release, a final fit test may be useful. At this stage, the test can verify any pattern or other changes that might have been made as a result of earlier testing. If the later stage test is the first time that all sizes of a sized item are available, then it provides a critical opportunity to test the smallest and largest sizes to verify that the grade is correct.

The later stage test is also used to prepare a size selection chart. While the product typically grows form size to size in a systematic fashion, the variation in human size and shape means that there is rarely 100% accuracy in predicting a person’s garment size from his/her body size. The late stage test allows the creation of a size selection chart that maximizes accuracy, while at the same time providing an estimate of how accurate the chart is. Additionally, the size prediction chart, when statistically overlaid on the target user population, can provide an estimated tariff for initial production.

3.3. Anthropometric dimensions

The point of an *anthropometric* fit test, as opposed to a generic fitting trial, is that the investigator will have anthropometric information about the test participants which can be correlated to the test results. The addition of this information is key in understanding how the product can be improved. There are two keys to successfully using anthropometric data from a fit test: dimension selection and measurement technique.

Choosing dimensions for anthropometric fit test should initially be based on critical fit areas. For example, in a chemical protective jacket, the sleeve length must be sufficient to reach the wrist where it can overlap with the glove. In this case, arm length from shoulder to wrist would be a critical dimension to measure. Depending on the item to be tested, an initial list of body dimensions can be created. Sometimes, when an item is totally new, it may not be clear what are the best human dimensions to be tested. In such cases, the investigator should err on the side of more, rather than fewer dimensions.

After the dimension list based on the item has been developed, then that list must be cross-checked against previously measured dimensions on the target population. It will be important in the analysis phase to demonstrate that the test sample captures the anthropometric range of the intended user population. In order to do that, the test sample and the user population must have some dimensions in common.

Finally, the test dimensions must be measured using the same techniques as were used on the intended user population. While some measurements – stature, for example – are typically measured in only one way, others vary considerably. Waist circumference can be measured at several different points; head length has varying definitions; hand length has multiple definitions. So prior to establishing the measurement techniques for the fit test, it is important to research the techniques used when the target population was measured, to make sure that the same techniques are used. If different techniques are used, then it will not be possible to determine whether or not the test sample captures the anthropometric range of the intended user population. While published anthropometric data vary in terms of how well documented the measurement techniques are, two sets of relatively complete measurement descriptions can be found in the National Center for Health Statistics (U.S.) and Clauser [9,10]

3.4. Test criteria

The best fit test criteria are those that are clearly defined, and repeatable from one test participant to another. Specifically, we recommend defining a certain range of acceptable fit for each of the critical garment areas. For example, in a one-piece coverall, the list of fit criteria is seen in Table 2.

Table 2. Example fit criteria for one-piece coverall.

Garment Area	Too Small/Too Short	Good Fit	Too Large/Too Long
Torso vertical circumference	< 1 inch	1 - 4 inches	> 4 inches
Chest ease	<3 inches	3 to 5 inches	> 5 inches
Waist ease	<3 inches	3 to 5 inches	> 5 inches
Hip ease	< 4 inches	4 to 7 inches	> 7 inches
Sleeve length	shorter than stylion	@ stylion up to 1 inch longer	> 1 inch longer than stylion
Leg length	shorter than 1 inch above lateral malleolus	within 1 inch above or 2 inches below lateral malleolus	> 2 inches below lateral malleolus

Note that there is a range for the good fit, and that values outside the range are either too short (small) or too long (large). Besides rating the fit at each area as either "Good", "Too small" or "Too Large", we recommend also taking and recording a specific measurement. So when data are analysed, we can say that the leg length was too short 47% of participants, and the amount by which it was too short ranged from ½ to 3 inches. With that level of detailed information, it is very clear how the pattern should be altered to improve the fit.

The fit criteria should be developed in consultation with the garment designer, and in some cases also in consultation with representatives of the intended user group. Fit is a complex concept, and not everyone will agree on each aspect of fit. A careful analysis of each area of the product's interface with the human will increase the likelihood that there are realistic, repeatable and meaningful fit criteria.

It is sometimes also desirable to solicit participants' opinions, especially about comfort, but sometimes also about fit. These opinions can add face validity to the test, but such opinions are typically not very helpful in making changes to improve the product. When soliciting participant opinion, it is generally preferable to ask the question in a 5-point scale ("uncomfortable" to "very comfortable", or similar) and to ask the question about a specific product-body interface. For example, rather than asking an overall comfort question about a jacket, one might ask, "On a scale of 1 to 5, how comfortable is the shoulder area?" If a significant number of participants rate the shoulder comfort as a 1 or 2, then it is a clear indication that something needs to change in the shoulder area, although it is not clear from that data what specifically should change.

4. Data analysis

Prior to any data analysis, editing of the raw data should be performed. This step can reduce or eliminate data entry errors, data recording error and other types of observer error. Using the edited anthropometric data, the first step is to demonstrate that the test sample captures the anthropometric variability of the intended user population. Figure 3 shows one approach to this analysis. The test sample is displayed against the intended user population. In this case, it shows that the test sample exceeds the lower limit of stature, but does not quite achieve the upper limit of stature or chest circumference in the population. When examining the garment fit data from the test, then, it would be important to make sure that the largest and longest sizes fit the test sample with room to spare. This analysis can also be useful in predicting the proportion of the target user population that will be accommodated by the item. In some settings, there is a specific accommodation target set by regulatory bodies. In general consumer items, however, increased market share is always desirable, but business decisions may indicate that a lower proportion of the population should be accommodated, and this kind of analysis is very helpful in providing the necessary information to make informed decisions.

After comparing the test sample with the population, the next step is to actually examine the item fit results against the body size for each specific fit area. In early stage testing, we would analyse each of the fit criteria independently, in order to be able to provide explicit recommendations to designers for changes that will improve the fit or accommodation. In addition to the specific recommendations for pattern changes, by comparing body size information to the best-fitting size information, it is also possible at this point to recommend the number of sizes needed to accommodate the desired proportion of the population.

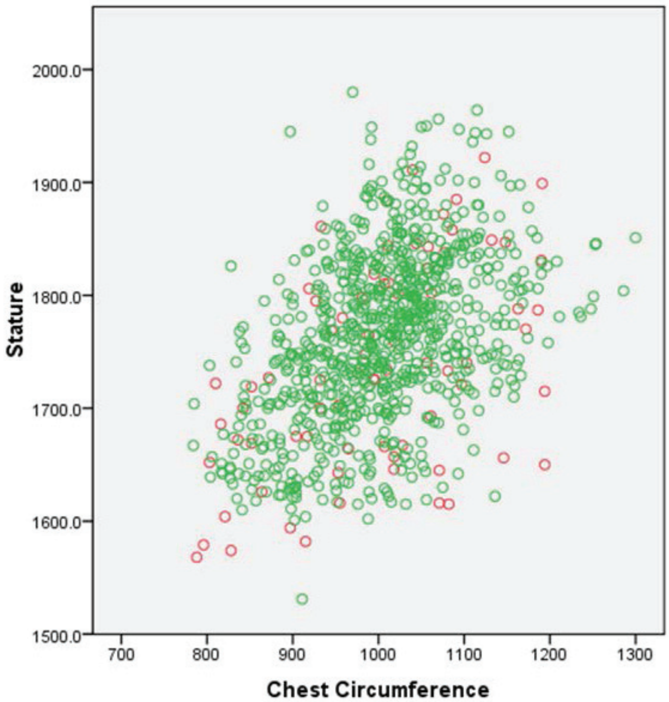

Fig. 3. Test sample (red) shown on intended user population (green).

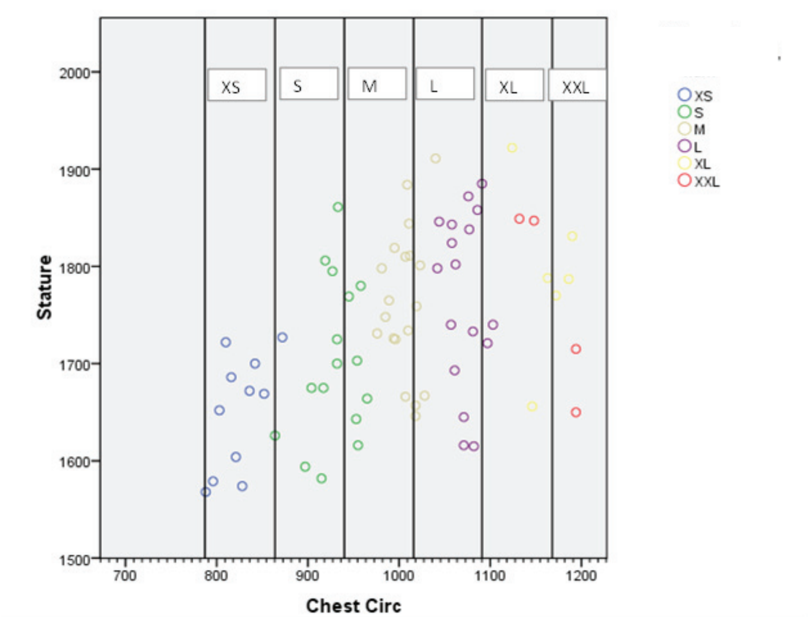

Fig. 4. Distribution of garment sizes used to create size selection chart.

For late stage testing, as noted above, the analysis goal can be to create and optimize a size prediction chart. Various multivariate analytical tools, such as cluster analysis or discriminant analysis can be helpful to determine which are the most effective predictor dimensions. In many cases, however, the test item is similar enough to other products that the specific predictor dimensions are known in advance. In these cases, the analysis is simply to maximize the predictive efficiency of the break points between sizes. A trial-and-error iterative process is typically the fastest way to get the most efficient result. Figure 4 shows the results of such an exercise.

Test participants were given several sizes to try on, and the best fitting size was determined, using the fit criteria. Then the best fitting sizes were plotted against key anthropometric dimensions, in this case chest circumference and stature. The data analyst then moves the dividing lines between sizes to the right and left to maximize the number correctly predicted. A count of those correctly predicted compared with those incorrectly predicted represents the accuracy of the chart. The chart itself is created by simply converting the location of the dividing lines into an easy-to-use table. As noted above, applying the break points to the overall population data will also produce an initial tariff.

5. Conclusion

A well-designed and well-conducted fit test can provide invaluable information to product designers and business decision-makers. The key components in creating and executing such a test are:

- Identifying critical body dimensions important in determining fit
- Choosing dimensions that are known on the population of interest
- Using the same measuring techniques on the test sample
- Developing an appropriate sampling plan
- Creating specific and repeatable fit criteria
- Analyzing edited data to produce specific recommendations for design changes and size prediction.

The use of this process will result in improved product design and increased user accommodation over traditional fit testing.

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